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MATHEMATICAL GUIDE TO THE TERMS AND DEFINITIONS FOR RELIABILITY OF ELECTRONIC EQUIPMENT AND COMPONENTS (OR PARTS) USED THEREIN

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MATHEMATICAL GUIDE TO THE TERMS AND DEFINITIONS FOR RELIABILITY OF ELECTRONIC EQUIPMENT AND COMPONENTS (OR PARTS) USED THEREIN

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 8 May 1975, after the draft finalized by the Reliability of Electronic and Electrical Components and Equipment Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard is a guide expressing in a mathematical form, reliability and its associated terms defined in IS : 1885 (Part XXXIX)-1974*. In this guide, only the quantitative reliability concepts are dealt with. The probability of failure of an item within a period of time can be expressed by the cumulative distribution function of times to failure. The characteristic values describing this distribution are assessed using a statistical approach.

0.3 The reliability terminology as defined applies equally well to large numbers of identical items, such as, transistors, resistors, etc, or just to a single unique item, for example, a data processing system. The items can either be repaired or not repaired after each failure.

0.4 This standard is largely based on IEC Publication 271(1974) 'List of basic terms, definitions and related mathematics for reliability' issued by the International Electrotechnical Commission.

0.5 This standard is one of a series of Indian Standards on reliability of electronic and electrical components and equipment.

1. SCOPE

1.1 This standard covers the mathematical concept and expressions for reliability and its associated terms.

*Electrotechnical vocabulary : Part XXXIX Reliability of electronic and electrical items.

2. SYMBOLS

2.1 A list of symbols which are used is given in Appendix A.

3. GENERAL

3.1 The distribution of times to failure of items which are not repaired, or the distribution of times between failures for items which are repaired, form the basis of definitions of reliability characteristic terms. These times are random variables which must be treated according to the usual methods of probabilitv calculus.

3.2 Where 'time' is used, this quantity can be replaced by distance, cycles or other quantities or units as may be appropriate. It may cover any duration of observation — either in actual operation or in storage, readiness, etc — but it excludes down time due to a failure.

3.3 For a continuous random variable X the probability that its value is less than or equal to a stated value x is given by the value of its 'cumulative distribution function' $F(X)$ where:

$$0 \leqslant F(x) \leqslant 1$$

The 'probability density function' $f(x)$ is defined by:

$$f(x) = \frac{dF(x)}{dx}$$

If x denotes time, then it is defined within the range from zero to infinity, so that:

$$\int_0^t f(x)\, dx = F(t), \text{ and}$$

$$\int_0^\infty f(x)\, dx = 1$$

3.4 Basic reliability concepts can be expressed in terms of these functions [$F(x)$ and $f(x)$]. In IS : 1885 (Part XXXIX)-1974*, the following time dependent reliability characteristics are defined:

a) Quantitative reliability,

b) Failure rate,

c) Mean time between failures (for repaired items) (MTBF),

d) Mean time to failure (for non-repaired items) (MTTF), and

e) Mean life (for non-repaired items).

*Electrotechnical vocabulary : Part XXXIX Reliability of electronic and electrical items.

These terms are expressed as 'observed', 'assessed', 'extrapolated' and 'predicted' versions. There also exists a 'true' value.

3.5 The concept of true values arises from an assumption that it is possible to describe reality by relevant mathematical models. The true values are characteristics of such a model. In practical situations, they can never be obtained by observations.

3.6 These values could also be thought of as those which would be obtained from the complete population taking into account the relevant part of the life histories of the items. (The origins of the lives do not necessarily occur at the same instant). In this case, the true values are often called population values.

3.7 Often it is either impractical or impossible to observe the complete population in order to obtain the population values. In some cases, it is necessary to perform tests which are destructive or degrading. In other cases, the complete population is not available at the time of the tests. For these reasons, items are taken from the population to form a sample. Observations are made on the sample in order to obtain statistical estimates of the true population values. Estimates are valid only if the sample is a random one. If observations were made on several samples, the estimates would vary from one sample to another, that is, the estimate is a random variable which itself has a normal distribution.

3.8 The 'observed' terms are defined in IS : 1885 (Part XXXIX)-1974*. Their values can be used as statistical estimates of the true reliability characteristics. Values for the 'assessed' terms, at stated confidence levels, are derived from the corresponding cumulative distribution function (if its form is known).

3.9 The times to failure of items, or the number of failures, in a sample, during a stated period of time, are the most commonly recorded quantities either during tests or during operation of equipment in the field. To obtain valid observed and assessed values of the reliability characteristics, which are representative of the population, all the relevant details (sample size, duration, stress conditions and failure criteria) must be truthfully recorded.

NOTE — This should be given in the relevant individual specification (*see* for example, IS : 7412-1974†).

3.10 The observed reliability characteristics may be extrapolated (or interpolated) by defined methods to cover durations and stress conditions differing from those for which the original observators were obtained. The observed, assessed or extrapolated reliability characteristics of parts may be used for the prediction of reliability characteristics of complex items.

*Electrotechnical vocabulary: Part XXXIX Reliability of electronic and electrical items.

†Life testing of semiconductor devices.

4. THEORETICAL EXPRESSIONS FOR THE TRUE RELIABILITY CHARACTERISTICS

4.1 General Expressions

4.1.1 The life of an item which is not repaired or time between failures for an item which is repaired is a random variable denoted by X.

4.1.2 As mentioned in **3**, the true values could reflect two concepts:

a) A mathematical model (this would be indicated by a single asterisk), and

b) Population values (this would be indicated by double asterisks).

4.1.3 In the case of both repaired or non-repaired items, the failure characteristics may depend on the age of the items. Practical application of reliability characteristics involves a given age, that is, a given period in their life histories. In practice, it may often be necessary to refer the age of an item not to the true beginning of its life, but to an arbitrary moment 'time zero'.

4.1.4 For repairable items, the reliability characteristics are valid for the period after the preceding repair.

4.2 True Reliability — The true reliability $R(t)$ is the probability P of an item surviving for a duration t, that is, its life x exceeds the duration t. It is given by:

$$R(t) = P (x > t)$$

It is related to the cumulative distribution function, $F(x)$, by:

$$R(t) = 1 - F(t)$$

In terms of population values:

$$R(t) = \frac{N(t)}{N(0)}$$

where

$N(0)$ = number of items in a population at time zero, and

$N(t)$ = number surviving at time t.

4.3 True Failure Rate and Instantaneous Failure Rate

4.3.1 The true failure rate $z (t_1, t_2)$ for a period of time from t_1 to t_2 is the quotient of the conditional probability, at the instant t_1, that an item will fail within the period, given that it has survived for time t_1 and the time period, that is:

$$z(t_1, t_2) = \frac{P (t_1 < x \leqslant t_2 / x > t_1)}{t_2 - t_1}$$

4.3.2 It is related to the cumulative distribution function and the true reliability by:

$$z(t_1, t_2) = \frac{F(t_1) - F(t_2)}{(t_2 - t_1)[1 - F(t_1)]}$$

$$= \frac{R(t_1) - R(t_2)}{(t_2 - t_1)R(t_1)}$$

$$= \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} z(t)\, dt$$

where $z(t)$ is the true instantaneous failure rate.

4.3.3 The true instantaneous failure rate at instant t, $z(t)$, is a mathematical concept. It is the limit of the true failure rate as the interval t_1 to t_2 tends to zero, and it is given by:

$$z(t) = \lim_{(t_2 - t_1) \to 0} z(t_1, t_2)$$

NOTE — $z(t)$ is also known as hazard rate.

4.3.4 It is related to the true reliability, $R(t)$, and the probability density function, $f(t)$, by:

$$z(t) = \frac{f(t)}{R(t)}$$

$$z(t) = -\frac{1}{R(t)} \frac{dR(t)}{dt}$$

since

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt}$$

4.3.5 In terms of population values, the true failure rate, often called mean or average failure rate, is:

$$z(t_1, t_2) = \frac{N(t_1) - N(t_2)}{(t_2 - t_1)N(t_1)}$$

4.3.6 There is no population value of instantaneous failure rate. This does not detract from the usefulness of the mathematical concept.

4.4 True Mean Life

4.4.1 The true mean life, $m_L(0, \infty)$, is the expected value, $E(X)$, of the life of an item.

It is given by:

$$m_L(0, \infty) = E(X)$$

or
$$m_L(0, \infty) = \int_0^{\infty} xf(x)dx$$

4.4.2 If $tR(t)$ approaches zero as t goes to infinity, $m_L(0, \infty)$ can be expressed by:

$$m_L(0, \infty) = \int_0^{\infty} R(t)dt$$

4.4.3 The true mean life $m_L(t_1, \infty)$ measured from a time t_1 is given by:

$$m_L(t_1, \infty) = \frac{\int_{t_1}^{\infty} xf(x)dx}{\int_{t_1}^{\infty} f(x)dx}$$

4.4.4 In terms of population values, the true mean life is given by:

$$m_L(0, \infty) = \frac{1}{N(0)} \sum_{i=1}^{N(0)} x_1$$

or
$$m_L(t_1, \infty) = \frac{1}{N(t_1)} \sum_{i=N(0)-N(t_1)+1}^{N(0)} x_1$$

where x_i is the life of the ith item.

4.5 True Mean Time Between Failures and True Mean Time to Failure — The true mean time between failures $m(t_1, t_2)$ and the true mean time to failure $m_F(t_1, t_2)$ are the mathematical expected values of the time between failures (for repaired items), or of the time to failure (for non-repaired items), respectively. The values so obtained will in general depend on the time period (t_1, t_2) over which they are computed.

4.6 Constant Failure Rate

4.6.1 When the failure rate is assumed constant with numerical value (as it is usual in reliability engineering), the times to failure are distributed exponentially. The true reliability is expressed as:

$$R(t) = \exp \left[- \int_{t_1}^{t_2} z(t)\, dt \right]$$

The true reliability becomes when constant failure is assumed:

$$R(t) = \exp (- \lambda t)$$

so that

$$F(t) = 1 - R(t) = 1 - \exp (- \lambda t)$$

and

$$f(t) = \lambda \exp (- \lambda t)$$

The true mean life becomes:

$$m_L = \int_0^{\infty} x f(x) dx = \frac{1}{\lambda}$$

4.6.2 In this case also the true mean life m_L, the true mean time between failures m and the true mean time to failure m_F are numerically equal to the reciprocal of the true failure rate, for the exponential distribution:

$$\text{that is } m_L = m = m_F = \frac{1}{\lambda}$$

5. EXPRESSIONS FOR THE OBSERVED RELIABILITY CHARACTERISTICS

5.0 The observed reliability characteristics are estimates of the true reliability characteristics, appropriate to the form of the cumulative distribution of times to failure.

NOTE — A list of estimators is under consideration.

5.1 Cumulative Time — The observed failure rate, mean time to failure and mean time between failures are all defined in terms of cumulative time. This is the sum of the times during which all the individual items under observation have been subjected to the stated stress conditions during a stated period in their lives (excluding any down time), for example, it may be expressed by:

$$T = \sum_{i=1}^{r} u_i + \sum_{j=1}^{k} v_j + hw$$

$$\text{for } 1 \leqslant i \leqslant r \text{ and } 1 \leqslant j \leqslant k$$

where $u_i < w$, $v_j < w$

and T = total cumulative time;

r = number of items which fail during the observation;

k = number of items added or withdrawn without failing during the observations;

h = number of items which survive for the whole period w;

w = duration of the stated period in the lives of the items;

u_i = duration for which the ith failed item was subjected to the stated stress conditions, within the period w; and

v_j = duration for which the jth non-failed item, added or withdrawn during the observations, was subjected to the stated stress conditions, within the period w.

NOTE — This definition is correct in itself for the case of items having constant failure rate. In other cases it may be necessary to refer the durations of stresses (u_i, v_j, w) to the relevant parts of the lives of items.

5.2 Observed Reliability

5.2.1 *Observed Reliability of Non-Repaired Items* — The observed reliability of non-repaired items is given by:

$$\hat{R}\,(t_1, t_2) = \frac{n - r}{n}$$

where

n = number of items in the sample at time t_1, and

r = number of items which failed during the period of time from t_1 to t_2.

5.2.1.1 If the observations or tests are terminated at the instant of the occurrence of the rth failure $\hat{t}'_r$ then the value of the reliabitity for this observed period of time $\hat{t}'_r$, is given by:

$$R\,(\hat{t}'_r) = \frac{n - r + 1}{n + 1}$$

which is determined by the test plan (that is, by the sample size n and the number of failures r chosen beforehand).

5.2.1.2 These expressions give the estimates which are valid only for the durations of observations (t_1 to t_2, or $\hat{t}'_r$) and the part of the life of

the items during which the observations were made. Any extension to different parts of lives can be made only if the form of the distribution is known.

5.2.2 *Observed Reliability of a Repaired Item or Items* — The observed reliability of a repaired item or items is given by:

$$\hat{R}\,(t'') = \frac{q - r}{q}$$

where

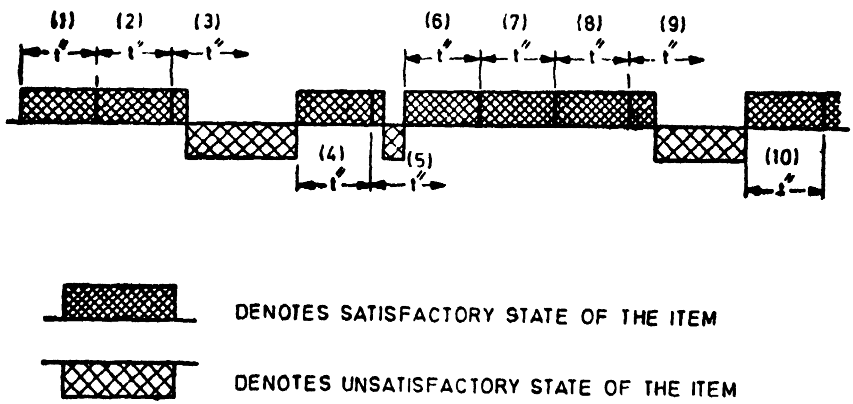
q = total number of occasions for which the performance was observed or tested,

r = total number of occasions when the item or items failed to perform satisfactorily for the whole duration of t'', and

t'' = duration of the period for which the reliability of the item or items was observed or tested.

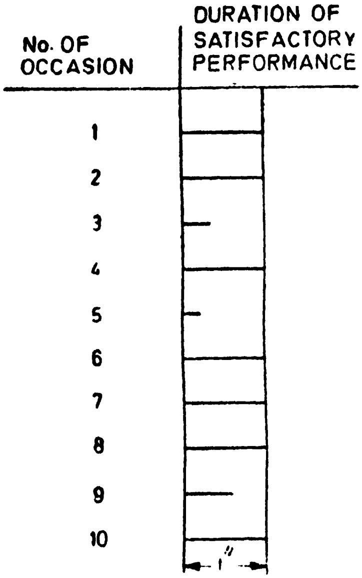
5.2.2.1 If an item is repaired after a failure, then the next period t'' starts with the moment of the resumption of the test or operation, even if the time of successful operation before the failure and the duration of the repair were shorter than t''. For example, for the case illustrated in the following diagram:

$$q = 10,\ r = 3,\ \hat{R}\,(t'') = \frac{7}{10}$$



1, 2, ... , 10 are the numbers of the consecutive occasions for which the performance was observed or tested.

This can be re-drawn:



5.2.2.2 Great care should be exercised in applying this estimate to durations other than t'' when the failure rate can be considered or suspected to be varying with the age of the item.

5.3 Observed Failure Rate, Mean Time to Failure and Mean Time Between Failures — As defined in IS : 1885 (Part XXXIX)-1974*, the observed failure rate, mean time to failure and mean time between failures are estimated for the true values for the case of the exponential distribution.

In this case, the observed failure rate $\hat{\lambda}$ may be given by:

$$\hat{\lambda} = \frac{r}{T}$$

For non-repaired items, the observed mean time to faiure $\hat{m}_F$ is given in **4.8.1** of IS : 1885 (Part XXXIX)-1974*:

$$\hat{m}_F = \frac{T}{r}$$

*Eletrotechnical vocabulary : Part XXXIX Reliability of electronic and electrical items.

For repaired items, the observed mean time between failures, $\hat{m}_r$ is given in **4.9.1** of IS : 1885 (Part XXXIX)-1974*.

$$\hat{m}_r = \frac{T}{r}$$

(Unbiased when observations are terminated after a fixed number of failures).

5.4 Observed Mean Life — For a sample of non-repaired items, tqe observed mean life, as defined in **4.6.1** of IS : 1885 (Part XXXIX)-1974* is given by:

$$\hat{m}_r = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where

x_i is the life of the *i*th item, and n is the size of the sample.

6. ASSESSED RELIABILITY CHARACTERISTIC TERMS

6.0 The values of the assessed reliability characteristics are the limits of confidence intervals, which may be one-sided or two-sided, at stated confidence levels. They are based on the same observations as the corresponding observed characteristics, and they depend on the observations, the choice of confidence level and, generally on assumed underlying distributions. The meaning of confidence intervals, confidence levels, etc, are as defined in **7.0.1** of IS : 1548-1969†.

6.1 General Case — Assessed Reliability for Non-Repaired and Repaired Items — Assessed reliability values for both non-repaired items [observations terminated at time t_2 (*see* **5.2.1**)] and repaired items may be obtained from the limits of confidence intervals for a known distribution using recognized methods. When they are obtained in this way, they are independent of the form of the distribution (such as, binomial and poisson) of the times to failure during the stated period of time.

6.2 General Case — Assessed Mean Life — For non-repaired items, the assessed mean life may be based on the sample size and the observed times to failure of all the items in the sample, using accepted statistical methods for mean values of random variables. The underlying probability distribution used should be selected on the basis of relevant past experience and of the distribution of the lives of the items in the sample.

*Electrotechnical vocabulary : Part XXXIX Reliability of electronic and electrical items.

†Manual on basic principles of lot sampling (*first revision*).

6.3 Special Case — Constant Failure Rate — In the case of the exponential distribution of lives or times between failures (that is, constant failure rate):

$$m_L = m = m_F = \frac{1}{\lambda} \text{ (\textit{see} \textbf{4.6})}$$

Thus the assessed mean life, the assessed mean time between failures and the assessed mean time to failure are numerically equal. The confidence limits which give the assessed values may be derived from the χ^2-distribution. However, other approaches are also possible.

6.3.1 For the one-sided interval, at confidence level ($1-\alpha$), the limits may be written $m_{S,\alpha}$ for the assessed mean time between failures and $\lambda_{S,\alpha}$ for the assessed failure rate, where:

$$m_{S,\alpha} \leqslant m \leqslant \infty$$

and

$$0 \leqslant \lambda \leqslant \lambda_{S,\alpha}$$

6.3.2 For the two-sided interval at confidence level ($1 - \alpha$), the limits may be written $m_{m,\alpha}$ and $m_{M,\alpha}$ for the assessed mean time between failures and $\lambda_{m,\alpha}$ and $\lambda_{M,\alpha}$ for the assessed failure rate, where:

$$m_{m,\alpha} \leqslant m \leqslant m_{M,\alpha}$$

and

$$\lambda_{m,\alpha} \leqslant \lambda \leqslant \lambda_{M,\alpha}$$

6.3.3 The assessed reliability may be obtained from the assessed mean time between failures or the assessed failure rate, using the expression:

$$R(t) = \exp (- \lambda t) = \exp (- t/m)$$

Let $\chi^2_\gamma(v)$ be the value of χ^2 (for v degrees of freedom) for which γ is the probability that:

$$\chi^2 > \chi^2_\gamma(v)$$

that is

$$P [\chi^2 > \chi^2_\gamma(v)] = \gamma$$

The expressions which shall be used to obtain the confidence limits depend on the criterion for stopping the observations.

6.3.4 For a fixed value of r, and a cumulative time T which is observed when this value is reached:

$$m_{S,\alpha} = 1/\lambda_{S,\alpha} = \frac{2T}{\chi^2_\alpha (2r)}$$

$$m_{m,\alpha} = 1/\lambda_{M,\alpha} = \frac{2T}{\chi^2_{\alpha/2}(2r)}$$

$$m_{M,\alpha} = 1/\lambda_{m,\alpha} = \frac{2T}{\chi^2_{1-\frac{\alpha}{2}}(2r)}$$

6.3.5 For a fixed cumulative time of observations, T, and a number of failures, r, which are observed during this time:

$$m_{S,\alpha} = 1/\lambda_{S,\alpha} = \frac{2T}{\chi^2_{\alpha}(2r+2)}$$

$$m_{m,\alpha} = 1/\lambda_{M,\alpha} = \frac{2T}{\chi^2_{\alpha/2}(2r+2)}$$

$$m_{M,\alpha} = 1/\lambda_{m,\alpha} = \frac{2T}{\chi^2\left(1-\frac{\alpha}{2}\right)(2r)}$$

APPENDIX A

(*Clause* 2.1)

LIST OF SYMBOLS USED

A-1. Only the symbols which are repeated more than once are listed here:

X = Continuous random variable

x = Value of X (usually the life of an item in this standard)

$F(x)$ = Cumulative distribution function of x

$f(x)$ = Probability density function of x

t = Time

$R(t)$ = Reliability for time t

$P(E)$ = Probability of event E

$N(t)$ = Number of items in a population surviving at time t

$N(0)$ = Number of items in a population at time 0

$z(t_1, t_2)$ = True (average) failure rate for period of time from t_1 to t_2

$z(t)$ = True instantaneous failure rate at instant t

$m_L(t_1, \infty)$ = True mean life for a period of time from t_1 to infinity

$E(X)$ = Expected value of X

x_i = Life of the ith item in a population or sample

$m(t_1, t_2)$ = True mean time between failures for a period of time from t_1 to t_2

$m_F(t_1, t_2)$ = True mean time to failure for a period of time from t_1 to t_2

λ = True constant failure rate — numerical value

m_L = True constant mean life — numerical value

m = True constant mean time between failures — numerical value

m_F = True constant mean time to failure — numerical value

T = Cumulative time

r = Number of failures

n = Number of items in a sample at the beginning of the period of observations

$\hat{R}(t_1, t_2)$ = Observed reliability for a period of time from t_1 to t_2 (time truncated)

$\hat{\lambda}$ = Observed failure rate (constant)

$\hat{m}_L$ = Observed mean life (constant failure rate)

$\hat{m}$ = Observed mean time between failure (constant failures rate)

$\hat{m}_F$ = Observed mean time to failure (constant failure rate)

$\chi^2_\gamma, (v)$ = Value of χ^2 (for v degrees of freedom) for which γ is the probability that $\chi^2 > \chi^2_\gamma (v)$

$1 - \alpha$ = Confidence level, c

$\left.\begin{matrix} m_{S,\alpha} \\ m_{m,\alpha} \\ m_{M,\alpha} \end{matrix}\right\}$ = Assessed constant mean time between failures at confidence level $1 - \alpha$ (single, lower and upper limits)

$\left.\begin{matrix} \lambda_{S,\alpha} \\ \lambda_{m,\alpha} \\ \lambda_{M,\alpha} \end{matrix}\right\}$ = Assessed constant failure rate at confidence level $1 - \alpha$ (single, lower and upper limits)

c = Confidence level, $1 - \alpha$

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Patliputra Industrial Estate, PATNA 800013	6 23 05
Hantex Bldg (2nd Floor), Railway Station Road, TRIVANDRUM 695001	7 66 37
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Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

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